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Excitation of Instabilities Due to an External Field

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Simulation Study of Ion-Cyclotron-Like Modes in a Magnetoplasma with a Transverse Inhomogeneous Electric Field

A new mechanism as discussed by Ganguli *et al.* [1985a, b; 1988] can destabilize electrostatic waves in the presence of a nonuniform electric field perpendicular to the uniform ambient magnetic field. When the electric field is nonuniform, it is possible for a finite region to contain negative wave energy surrounded by regions of positive wave energy. A nonlocal wave packet couples the two regions so that a flow of energy from a region of negative wave energy to a region of positive wave energy will cause the mode to grow. This gives rise to the instability.

The ion-cyclotron instability is important to both space and laboratory plasma. In most of the previous studies, field-aligned currents or ion beams have been cited as the driving mechanism [see, *e.g.*, Okuda and Nishikawa, 1984]. Recently, some laboratory experiments [Nakamura *et al.*, 1984] have reported ion-cyclotron instabilities in circumstances where neither of the above processes provide a satisfactory free-energy source, and the existence of a two-dimensional electric field is conjectured to play a role. Furthermore, unstable ion-cyclotron waves have been reported in connection with double layers [Merlino *et al.*, 1984; Alport *et al.*, 1986] and electrostatic shocks [Temerin *et al.*, 1981]. In all cases, a localized electric field perpendicular to the external magnetic field is an intrinsic feature of the equilibrium.

Nishikawa *et al.* [1988b] have investigated this new mechanism for an instability by means of simulations in the presence of a nonuniform electric field perpendicular to the uniform magnetic field associated with a density gradient. A two-dimensional electrostatic code was used which retains the full dynamics of the ions in three dimensional velocity space. Electrons are treated

by the guiding center approximation in the perpendicular direction while the parallel motion is treated exactly. We used a system length $L_x = 128\Delta$, and 64Δ, where Δ is the grid size which is equal to the electron Debye length. λ_e and $\overline{n}_e\lambda_e^2 = 36$. The external electric field is applied in the form of $E_{ox}(x) = E_{ox}\mathrm{sech}^2[(x-64)/L]$ in the x direction which produces $E \times B$ drift in the y direction given by $V_E(x) \simeq -E_{ox}(x)/B_o$. For the purpose of initial loading in a computer simulation, the distribution can be expressed in terms of the physical position x (for details, see Ganguli *et al.* [1988]),

$$2\pi f_{o\perp} = \frac{\beta \exp\{-\frac{\beta}{2}[v_x^2 + \frac{(v_y - V_E(x))^2}{\eta(x)}]\}}{\sqrt{\eta(x)}}[1 + O(\epsilon)], \tag{1}$$

where $\eta(x) = 1 + V_E'(x)/\Omega$ and $[\,]' = d[\,]/dx$. It is interesting to note that the distortion in the gyro-orbit introduced by the sheared transverse d.c. electric field leads to a sustainable difference in the temperature in the two dimensions transverse to the uniform magnetic field.

Other parameters used are $B_{oy}/B_o (= k_{||}/k_y) = 0.0075$, $\Omega_e/\omega_{pe} = 4$, $T_i/T_e = 3.5$, $m_i/m_e = 100$, $L = 11\Delta$, $\alpha = E_{ox}^2/4\pi\overline{n}_e T_e = 0.2$, *and* $V_E^o = 0.59 v_{it}$ where $\overline{n}_e$, V_E^o, and v_{it} are the averaged electron density, the peak value of $V_E(x)$ and the ion thermal velocity, respectively.

The time evolutions and their spectra are shown for the modes (0, 3) which corresponds to $b = 1.89$, $k_y\rho_i = 1.37$, $k_yL = 3.23$ and (0, 4) which corresponds to $b = 3.38$, $k_y\rho_i = 1.84$, $k_yL = 4.31$. The mode (0, 3) begins to grow clearly and emerge from the background thermal noise around $\Omega_i t = 150$ and goes into the nonlinear stage around $\Omega_i t = 300$. The detailed wave analysis shows that in the linear stage this mode has real frequency around $0.5\Omega_i$. The peak of the frequency spectrum is located around $0.2\Omega_i$. The frequency of this mode becomes lower in the nonlinear stage. This is a common feature for all modes. The real

frequency of the (0, 4) mode saturates around $0.6\Omega_i$, also we find a number of smaller peaks around higher harmonics.

An estimate of the growth rates of several modes in order to identify the fastest growing mode indicates that the mode (0, 4) which corresponds to $b = 3.38$, has the maximum growth rate $\gamma/\Omega_i \sim 0.025$. We plotted the estimated growth rates of the (0, 1) to (0,5) modes against b. It should be remarked that the mode (0, 1) which corresponds to $b = 0.21$ and $k_y L \simeq 1$, and falls on the K-H branch has a smaller growth rate ($\gamma/\Omega_i \sim 0.015$) than the higher modes which form the new branch. Clearly it is the ion-cyclotron-like branch with the mode (0, 4) that actually dominates. The maximum growth rate of this ion-cyclotron-like mode is located around large b (= 3.38 and $k_y L \sim 4$) and large real frequency ω_r ($\sim \Omega_i$, in the linear stage). Thus, unambiguous distinction is made between the kinetic K-H mode and the new ion-cyclotron-like mode. Besides, we have identified both the branches of the system in our simulation and for the given set of parameters we find that the dominant mode does not belong to the K-H branch; instead on the new I-C-like branch which has higher frequency and shorter wavelength.

Nonlinear phenomena such as diffusion and coalescence of vortices are investigated. In the linear stage smaller vortices are generated and larger vortices with the lower frequencies are dominant in the nonlinear stage. In the nonlinear stage ions diffuse strongly due to large-scale vortices.

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